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A Publication of the Society of Economic Paleontologists and Mineralogists
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DECEMBER, 1932

TEXAS FULLER'S EARTHS

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ABSTRACT

Petrographic work on the fuller's earths of Texas has led to the following conclusions: (1) These fuller's earths are derived from volcanic dust and tuff and are bentonites in the strict sense of the term. (2) The source of the many Tertiary materials is the same as that of the Catahoula tuffs to the southwest, while the source of the one Cretaceous deposit investigated cannot be determined at present. (3) The mineral of the fuller's earths is related to the minerals of the montmorillonite-beidellite group but represents a species as yet undescribed.

INTRODUCTION

Recent advances in mineralogical and petrographical methods of research have created a new scientific and commercial interest in the exact nature of the clays commonly known as fuller's earths, and has made possible a more accurate study and classification of them. The clays included in this study are the materials which are generally known as fuller's earths in Texas and which are suitable for the industrial purposes for which fuller's earth is used. They represent materials from every commercial deposit of fuller's earth worked in the state during the year 1931.

The following is a list of pits from which samples of fuller's earth for study were collected and their locations:

The Womack pit is in Grimes County and may be reached by following the Anderson-Bedias highway for a distance of 1.9 miles, the Carlos road for four miles, then a farm road for 1.5 miles to a farm house and the pit.

The Kenard pit, also in Grimes County, may be reached by the following route: 1.9 miles on the Anderson-Bedias road; 3.6 miles on the Carlos road; then about three-eighths of a mile on a side road.

The Texas Company's Riverside plant is on the west edge of Riverside, Walker County.

The Continental Oil Company's Riverside plant is one mile northwest of the town.

The Lauderdale pit is about 5 miles west of Somerville in Burleson County.

The Lena pit is at the railroad switch at Lena, Fayette County.

The Medina fuller's earth is in the Taylor formation of Upper Cretaceous age in Medina County.

ACKNOWLEDGMENTS

This problem was chosen at the suggestion of Dr. John T. Lonsdale, who collected the samples examined in this study, and to whom the writer is indebted for use of data concerning the occurrence of the fuller's earths and

for many valuable suggestions during the course of the work.

STRATIGRAPHIC POSITION OF THE FULLER'S EARTHS

The fuller's earths collected for the present study were with one exception —the sample of Medina clay—collected from a fairly narrow belt extending from Karnes County northeast to a point near Anderson, Grimes County, in the Coastal Plain of Texas. This belt parallels the general strike of the Tertiary strata in this part of the Gulf Coastal Plain and corresponds roughly with the belt occupied by the Catahoula (Miocene) and Fayette (Eocene) formations. The Catahoula to the south of Karnes County is composed of volcanic tuffs and was described as the Gueydan formation[1], a name which has since been abandoned. The formation northeast of Karnes County consists of blue quartzose sandstones, calcareous cross-bedded sandstones, sandy clays, bedded sandstones, and massive "talc-like" clays[2], which have a greasy luster and soapy feel. The fact, as shown herein, that the fuller's earths represent deposits of volcanic dust coincides nicely with the two facies of these strata. The volcanic tuffs of Bailey's "Gueydan" show a gradual transition to finer material to the northeast and in Karnes County the volcanic material changes to dust mingled with detrital sediments.

Some of the fuller's earth deposits are probably higher and some probably lower in the stratigraphic column than most of the material generally included in the Catahoula. As the eruptions were probably several in number this does not invalidate the conception that all the deposits came from the same ultimate source. The eruptions may have started furnishing dust to the more distant places of deposition before the apparent beginning of Fayette deposition in those places; and may have lasted slightly longer than the particular period of time generally assumed to be the later limits of Catahoula time at those more distant places. No exact age determinations of the Tertiary strata bearing many of the fuller's earths have yet been made.

The Medina fuller's earth is in the Taylor formation of Upper Cretaceous age. Many Upper Cretaceous volcanoes were in existence in various parts of the general region which could have furnished the volcanic dust of which this fuller's earth is an alteration product. Numerous deposits of bentonite have been reported from Upper Cretaceous beds in the region.[3]

PETROGRAPHY

The fuller's earths studied are characterized by relict structures of the primary materials, which are excellently preserved, in many cases, in the form of clay minerals. Thin sections prepared from the fuller's earths were compared with published photographs

[1] Bailey, T. L., The Gueydan, A new middle Tertiary formation from the Southeastern Coastal Plain of Texas, *Texas Univ., Bull.* 2645, 1926.

[2] Deussen, A., Geology of the Coastal Plain of Texas West of the Brazos River, *U. S. Geol. Survey, Prof. Paper* 126; *Univ. of Texas Reprint*, 1930, p. 100.

[3] Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma and northeastern Texas, *U. S. Geol. Survey, Prof. Paper* 154-F, 1929.

of volcanic dust[4], bentonite[5], altered volcanic rocks of Paleozoic age[6], and with thin-sections of volcanic dust made in the laboratory. Without exception the relict structures show that materials investigated were originally mainly volcanic dust, most of which is now devitrified, but many shards of volcanic glass in all stages of alteration to clay minerals are present. Numerous devitrified, uncollapsed bubble walls, lune-shaped figures, crescent-shaped particles, and irregular fragments resembling those seen in thin sections of volcanic dust and bentonite are present.

Materials other than clay minerals in the fuller's earths include angular quartz grains, zircon, feldspars, calcite, possibly apatite, foraminifera, fossil leaves, lignite, and numerous diatoms probably composed of opaline silica. Fragments of amorphous material of low index of refraction were determined to be opal.

One sample yielded a small fragment of crystalline mineral resembling feldspar which had attached to it cleavage flakes of a mineral resembling a clay mineral of low double refraction.

One specimen of fuller's earth from Lauderdale is generally referred to as bentonite. The name probably has been applied to this particular material because of its close resemblance to other bentonites of the Coastal Plain of Texas. Like many Texas bentonites, this material has the property of breaking down rapidly when placed in water. This specimen is less contaminated by detrital materials than most of the other clays under consideration. It also shows more and better relict structures of volcanic dust than do the other specimens studied. The clay minerals in this specimen occur in large, easily cleaved crystalline flakes.

Two clays known as "gray earth" and "brown earthy material" from Lena show many partially altered shards of glass, ghosts of former crystals, partially altered crystals of feldspar, angular quartz grains some of which have inclusions resembling zircon, and a very fine-grained mineral of bluish tint in transmitted light which may be anatase.

Numerous small veinlets composed of crystals of clay minerals much larger than the surrounding groundmass are present. These are suggestive of minute cracks along which solutions that aided in the building of larger crystals may have passed.

Fuller's earths from two pits at Riverside were very nearly similar. Numerous shards of volcanic glass, devitrified bubble walls, and long, thin fragments of crystalline material suggestive of crystalline clay minerals formed *in situ* are present. Small veinlets of relatively large crystals cut the otherwise very fine-grained groundmass. Several ghosts of former crystals are preserved in the fine-grained material, the particles being somewhat coarser in the area occupied by the crystal.

[4] Johannsen, A., *A descriptive petrography of the igneous rocks*, vol. 1, Chicago, 1931, p. 7.

[5] Ross, C. S., and Shannon, E. V., Minerals of Bentonite and related clays and their physical properties, *Jour. Am. Ceramic Soc.*, vol. 9, no. 2, 1926, pp. 82-83.

[6] Ross, C. S., Paleozoic volcanic materials and criteria for their recognition, *Bull. Am. Assn. Petroleum Geol.*, vol. 12, 1928, pp. 143-164.

Clay from the Lauderdale pit, the Kenard pit, and the Simon pit also show crystalline clay minerals of high birefringence intermixed with partially altered fragments of volcanic dust, angular quartz grains, a small amount of zircon, and other detritals.

The clay from the Lauderdale pit mentioned above contains an abundance of fossil leaves, lignite, and other organic remains. Specimens from the Simon pit consist of masses of a brownish clay of earthy luster and soapy feel in which is embedded angular masses of a soft clay of greasy luster, many of which measure approximately one centimeter in diameter. These fragments, which are fairly numerous, make the rock resemble a volcanic tuff which has been altered to clay minerals. The clay mineral in the small embedded masses resembles optically the mineral of the matrix.

The fuller's earth from Medina contains more impurities than most of the other specimens studied. The same bentonitic texture is present, however. Many devitrified uncollapsed bubble walls, crescent-shaped masses, and shards of volcanic glass are present. Angular fragments of quartz, tourmaline, calcite, and a greenish brown mineral resembling amphibole are present. Foraminifera composed of calcite and resembling in section members of the genera *Guembelina* and *Globigerina* are present. The matrix of this rock is very coarse-textured compared with that of the other specimens examined.

MINERALOGY

The essential minerals of the fuller's earths studied belong to a type of clay mineral or group of clay minerals resembling optically those of the montmorillonite-beidellite group as described by Ross and Kerr[7] and which can only be distinguished from members of this group by their x-ray diffraction patterns. After optical properties were determined samples of the material from two pits at Lena and two places at Riverside were submitted to Dr. P. F. Kerr of Columbia University for x-ray examination. The following is quoted from Dr. Kerr's report:[8]

> I believe that the x-ray diffraction patterns clearly indicate that all four samples submitted represent the same mineral type of clay. Furthermore, the type does not appear to be either a kaolin or a montmorillonite type of clay.
>
> The four samples appear to agree with the sedimentary clay type mentioned in our recent paper in the *Journal of Sedimentary Petrology*.[9] This type of clay may not represent a valid mineral species. We have not yet determined whether it represents a distinct mineral. . . . The x-ray patterns give numerous lines that do not resemble the lines of any other clay minerals.

Both clays from the Riverside and Lena deposits are characterized by high double refraction. The mean index of refraction of the Riverside is close to 1.523 and seems to vary within comparatively narrow limits on different flakes of material. Some flakes from the same specimen have a slightly higher index of refraction. Flakes of mineral from the Lena deposit have an index of refraction slightly under 1.5006 with a few particles running

[7] Ross, C. S., and Kerr, P. F., The clay minerals and their identity, *Jour. Sed. Petrology*, vol. 1, no. 1, 1931, pp. 55-65.

[8] Kerr, P. F., Letter of May 21, 1932, to Dr. J. T. Lonsdale.

[9] Ross, C. S., and Kerr, P. F., *op. cit.*

slightly higher. These indices of refraction correspond to the range of indices of refraction of minerals included in the montmorillonite-beidellite group. It should be noted that the measured indices of refraction of all members of this group vary considerably.[10]

The clay constituent of the so-called "bentonite" from Lauderdale has an index of refraction of 1.488. Some flakes of deeper pink run slightly above this figure while lighter colored flakes run slightly below.

A highly double refracting mineral with index of refraction of some flakes close to 1.505, while a few run higher and lower, composes the fuller's earth known as the Lower Blue Clay from Somerville.

The clay mineral of the fuller's earth from Medina has a high double refraction and an index of refraction approximately the same as that of the Lower Blue Clay from Somerville.

Material from the Simon pit is composed of a clay mineral with an index of refraction near 1.523.

The clay mineral from the Kenard pit has a high double refraction and an index of refraction slightly above 1.5218.

It will be noted that the minerals of the fuller's earths have indices of refraction which vary considerably between a certain maximum and minimum. Some of these indices suggest montmorillonite, some beidellite, while others fall within the range of both these minerals. Since, however, the x-ray patterns have shown the minerals of the Lena and Riverside clays to be related to the unnamed clay mineral resembling this group optically, and since the minerals in the clays from other localities are similar to those found in the Lena and Riverside clays, it would be unsafe to assign either the name montmorillonite or beidellite to the minerals of these clays until all specimens can be submitted to x-ray analysis.

[10] Ross, C. S., and Shannon, E. V., *op. cit.*

CONCLUSIONS

It has been shown that the fuller's earths of Texas have the same textures as bentonites and are derived from the devitrification of volcanic dust and tuffs which were mingled during deposition with small percentages of detritals. Therefore these fuller's earths are bentonites in the strict petrographic sense of the term.[11]

The essential mineral of the fuller's earths studied is similar optically to the clay minerals of the montmorillonite-beidellite group. X-ray diffraction patterns show the mineral to correspond to a doubtful species as yet undescribed.

[11] Since the above work was completed Dr. P. F. Kerr has published essentially the same conclusions in regard to the fuller's earths from Woburn Sands, England, and Cilly, Styria. See Kerr, P. F., Montmorillonite or Smectite as constituents of Fuller's Earth and Bentonite, *Am. Mineralogist*, vol. 17, 1932, pp. 192-198.

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DECEMBER, 1932

THE MECHANICAL ANALYSIS OF FINE-GRAINED SEDIMENTS[1]

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ABSTRACT

Older methods of mechanical analysis are briefly discussed and contrasted with the newer precision methods. The pipette method is chosen from the latter as one based on sound principles and yet simple in operation. The principles of the method, its range of application, and inherent sources of error are taken up. A standardized routine for the preparation of samples for analysis is described, and a comparison is made of the pipette method with one of the older routine methods. A flow sheet, indicating in graphic form the steps involved in analyzing a sediment, is appended.

INTRODUCTION

Among the methods which have been used for the mechanical analysis of fine-grained sediments are two which have been most widely applied by sedimentary petrologists. These are the decantation or sedimentation method, and rising current elutriation. There are certain disadvantages to both of these methods, which have long been recognized. The decantation method suffers from the difficulty of obtaining a complete separation of the finer material from any grade size, and the long settling-periods and large number of decantations necessary among the smaller ranges introduces a serious element of tediousness. Rising current elutriation, while eminently suitable for the silt sizes above the limit where flocculation is effective, suffers also from the practical impossibility of separating very fine grades by its means. Neither of these methods is suitable for material much below 0.01 mm. in diameter, and in the case of sediments whose particles lie wholly below this diameter, they are valueless.

In recent years soil scientists have perfected numerous devices for the determination of the finer components of soils, many of which are equally applicable to sediments. These newer precision methods differ from the older techniques in at least one striking manner; the older methods endeavored to separate the various grades as units, while the newer ones do not. This modern approach to the problem was first made by Odén in 1915, when he showed that the size distribution of soils could be determined from a curve based on the weight of sediment accumulating at the base of a column of suspension, as a function of the time. For the practical application of the method he devised his continuous sedimentation balance. In 1918 Wiegner developed a continuous sedimentation cylinder in which the hydrostatic pressure at a fixed point

[1] Published with the permission of the Chief, Illinois State Geological Survey.

below the surface of the suspension was measured as a function of the time, and the curve so obtained served in a manner similar to Odén's curves as a means of determining the size distribution. Numerous other devices based on measurements of hydrostatic pressure or of density at some point in the suspension have been advanced since. A review of these developments has recently been published by the writer.[2]

THE PIPETTE METHOD

The apparatus used in many of the newer techniques is quite expensive, and a precision method embodying the soundness of principle of the others, but having the advantage of low cost and simplicity of operation, would be preferable to a majority of workers. Fortunately, such a method has been introduced in recent years. It is the pipette method established independently in 1922 by Robinson in England, Krauss in Germany, and Jennings, Thomas, and Gardner in America. In its bare essentials the method consists of preparing a suspension of known concentration, and permitting it to rest until all particles greater than a given size have settled 10 cm. below the surface. The suspension is then sampled at this level with a 10- or 20-cc. pipette, and the sample dried and weighed. The suspension is shaken again, and allowed to rest until the next smaller sized particles have settled 10 cm. below the surface. Another pipette sample is withdrawn, and the weight of the dried residue determined. By subtracting the weight of the second residue from that of the first, the amount of material in the intermediate grade is found. A multiplying factor, based on the proportion of the pipette to the total volume, converts the results into terms of the total sample.

The principles upon which this method is based have been discussed by its originators, but a brief summary may not be amiss here. It rests upon the assumption that in a dilute suspension the particles settle as individuals, an assumption which is inherent in any method of analysis. If a suspension is thoroughly shaken so that the particles are uniformly distributed, and then set at rest, all particles having a settling velocity greater than h/t will have settled below a plane of depth h below the surface, at the end of an interval of time t. All particles having a velocity less than h/t, however, will remain in their original concentration at depth h, because they will have settled only a fraction of this distance in time t. If a small sample is taken from this depth at time t, and evaporated to dryness, the weight of the residue will represent the total amount of material having settling velocities less than h/t, after the weight of the residue is multiplied by a factor based on the proportion of the sample to the total volume of suspension.

After the first sample has been taken, the suspension is shaken again, and a greater period of time is allowed to elapse, so that particles of a next smaller size may settle below depth h. The second pipette sample will then contain a residue smaller than that of the first sample by an amount equal to the weight of material lying between the

[2] This *Journal*, vol. 2, pp. 89-124, 1932.

two chosen velocities. The process may obviously be repeated, and by simply subtracting the weights of successive residues, the amount of material in any grade may be determined directly.

In order to translate settling velocities into radii, recourse may be had to Stokes' law, in which $v = Cr^2$, where C is a constant under any given set of conditions. The constant may be evaluated for a standard set of conditions, and the only requisite is then that all analyses be run under these same circumstances. The writer has evaluated the constant for 20°C., assuming an average specific gravity of the sediment equal to 2.65. With these limiting conditions the value of the constant is 3.57×10^4, and by multiplying the square of the radius in cm. by this constant, the settling velocities in centimeters per second are obtained. The velocities are then converted into hours, minutes, and seconds required for a particle to settle a depth of 10 cm., by using the formula $v = h/t$. In practice it is convenient to use a single computation, where $t = h/Cr^2$.

It is obvious that the radii determined by Stokes' law are in terms of spheres, and in order to correct for the effects of non-spherical shapes, many writers have proposed various additive factors, or have simply ignored Stokes' law, and used average hydraulic values to represent given radii. In order to obtain some standardization, and to allow comparisons to be made, the writer would like to suggest the adoption of Odén's "equivalent radius," in which the settling velocity of any shaped particle is expressed in terms of the radius of a sphere having the same settling velocity. This appears to be a logical solution of the difficulty, because it furnishes a standard basis for reporting analyses, and yet permits individual workers to add such corrective factors as they wish to the basic data obtained. Such a concept as that of the equivalent radius is not a radical departure, because even in the sieving of sediments the shapes of particles determine in part their distribution, and an implied acceptance of an "equivalent radius" is universal among workers. It seems eminently desirable, therefore, that a similar concept be adopted for grades separated by their settling velocities.

TABLE SHOWING TIME REQUIRED FOR PARTICLES TO SETTLE H CENTIMETERS, ON BASIS OF PRINCIPLE OF EQUIVALENT RADIUS*

Diameter in mm.	Velocity in cm./sec.	H in cm.	Hrs.	Min.	Sec.
1/32	0.08688	10	0	1	55
1/64	0.02172	10	0	7	40
1/128	0.00543	10	0	30	40
1/256	0.001357	10	2	2	40
1/512	0.000339	10	8	10	40
1/1024	0.0000847	5	16	21	20
1/2048	0.00002117	5	49	25	20
1/10,000	0.000000892	5	1560	36	0

* The values in the table are based on a temperature of 20°C., and an average specific gravity of the sediments equal to 2.65.

On the basis of an equivalent radius, the writer has computed the necessary values for the pipette method in terms of the generally-adopted Wentworth grade-scale. These values are shown in the accompanying table, which presents the diameter of the particle, the settling velocity according to Stokes' law, and the time in hours, minutes, and seconds for the particle to settle a given depth under the assumptions that the temperature is 20°C., and the average specific gravity 2.65. It will be noted that the first several values are computed to a depth of 10 cm., and the last several to a depth of 5 cm. This change in the depth of sampling was made in order to reduce the time of settling to a more reasonable figure.

The values given in the table range from diameters of 1/32 mm. to 1/10,000 mm. The choice of these limits was governed by the limits of applicability of Stokes' law. According to Gessner;[3] the upper limit of validity of Stokes' law is a diameter of about 0.05 mm., which lies between the 1/16 and 1/32 mm. limits in the grade-scale. According to Von Hahn,[4] Stokes' law is valid to within the limits of the colloidal state, despite Brownian movement, although a lower limit probably must be present, or colloidal suspensions would not be practically permanent, as they are. The limits of the colloidal state have been generally accepted to lie between 0.1 μ and 0.2 μ diameter, so that the smallest diameter shown in the table, which is 0.1 μ, is perhaps as small as one may safely go. It is doubtful whether many sediments will be analyzed to this small size, because of the time involved.

These limits to the satisfactory operation of the pipette method require a special treatment of sediments having material larger than 1/16 mm. diameter. In such cases, as will be described in detail below, the coarser material is sieved from the sample before the standard suspension for pipetting is prepared. Sieves with meshes as small as 0.061 mm. are available at no great cost, and the writer has adopted the practice of using such a sieve to separate the samples into two parts, one for sieving, and the other for pipetting.

Another point that has a practical bearing on the accuracy of the pipette method concerns the nature of the sample obtained by the pipette. From purely theoretical grounds it is clear that the level sampled should be a horizontal stratum of depth h and essentially infinitesimal thinness. Practically, of course, a pipette taps a spherical zone, and various workers have endeavored to determine the amount of error introduced by this fact. The most outstanding contribution was made by Köhn,[5] who photographed the process of pipette sampling, and was able to determine with some degree of accuracy the zone affected. He concluded that since part of the sphere is above the theoretical stratum, and part below, the error was essentially compensatory. Gessner[6] discussed his findings, and pointed out that the error was of

[3] Gessner, H., *Die Schlämmanalyse,* p. 21.
[4] Hahn, F.-V. von, *Dispersoidanalyse,* p. 272.
[5] Köhn, M., Beiträge zur Theorie und Praxis der mechanischen Bodenanalyse, *Landwirts. Jahrb.,* vol. 67, pp. 485-546, 1928.
[6] Gessner, H., *op. cit.,* pp. 79 ff.

such a low order of magnitude that for a depth of 10 cm., and a sample of 10 cc., the error introduced was only 0.04 per cent. Keen[7] has concurred in showing that the errors are practically negligible. The fact that the pipette method has been adopted as standard for soil analyses in England, America, and by an international commission, argues strongly in its favor.

Special devices for withdrawing the samples have been developed, but an ordinary pipette with a rubber tube for suction affords fully reliable results.

THE TECHNIQUE OF ANALYSIS

Since the pipette method involves a continuous sedimentation of the particles acting as individuals, it is clear that complete dispersion of the sample is an integral part of the method. A great number of techniques for securing dispersion have been advanced, but it is generally agreed that a thorough disaggregation of the particles, followed by their peptization through chemical agents, is the most satisfactory. The two steps have often been combined into one, but it appears to be advisable to take into account the nature of the material being analyzed in adopting a particular technique. The writer's experience has been confined mostly to glacial tills and other unconsolidated sediments like lake clays, and for such sediments the process to be described has proved to be consistently satisfactory.

Experiments with several methods of disaggregation have convinced the writer that a period of shaking in a machine like that described by Briggs, Martin, and Pearce[8] gives consistently good results. In lieu of this, pestling with a rubber-covered pestle or with a stiff brush may be substituted. In the procedure adopted, shaking a quartered sample for one hour with 100 cc. of a one per cent solution of sodium carbonate has been found sufficient to break up the aggregates and to leave the coarser grains free of any adhering clay. The weight of the sample used depends upon the amount of material greater than 1/16 mm. present in it. It is desirable to have a final concentration between 2 and 3 per cent for pipetting, so that the proportion of fine material in the quartered sample should lie between 20 and 30 grams for a liter of suspension.

After the sample has been shaken for an hour, it is poured through a sieve with meshes of 1/16 mm. (0.061 mm.), and the residue on the sieve is washed with a gentle stream of water. A liter beaker is used to collect the washings, and care should be exercised to keep the volume below 1000 cc. when the process is completed. The material on the sieve is washed into filter paper, dried, and weighed. The difference in weight between the original sample and the sieve residue is the amount of material finer than 1/16 mm.

In many cases shaking, combined with the peptizing effect of sodium carbonate, is sufficient to produce a completely dispersed suspension, but the results obtained are not always consistent even among samples of similar

[7] Keen, B. A., *The physical properties of the soil*, p. 73.

[8] Briggs, L. J., Martin, F. O., and Pearce, J. R., The centrifugal method of mechanical soil analysis, *U. S. Dept. Agric., Bureau of Soils*, Bulletin 24, 1904.

sediments. With tills it was found that complete dispersion could in many cases be induced only by heating the final suspension to the boiling point, but not allowing it to boil. The boiling of samples has many advocates and a number of critics; Von Hahn,[9] indeed, refers to the "barbaric" practice of boiling suspensions, but others, such as Gessner,[10] recognize its merits in some cases. There is little question that prolonged boiling coagulates some of the colloids, but it may be equally true that an increase in temperature, within certain limits, enhances the peptizing effect of the dispersing agent. To test this, the writer has heated samples to 60°C., and 80°C., but without effects as permanent as at 100°C. Some of the suspensions prepared by the adopted method still retain their colloids in suspension after a period of one year. After the preliminary treatment has been completed, the suspension is poured into a liter graduate and diluted to 1000 cc.

Various methods have been used to test for flocculation in a suspension, and among these one of the simplest is to place a drop on a slide and examine it under the microscope. If each grain stands out as an individual, and the smaller ones display Brownian movement, it is reasonably safe to consider the dispersion complete, while if aggregates or bead-like strings of particles extend through the field, the suspension is flocculated. The test is not always positive in the absence of flocculles, because with small amounts of flocculants the suspensions may remain apparently dispersed for several hours. The writer has adopted the practice of preparing the following day's suspensions in the afternoon, and allowing them to stand overnight. If visible flocculation has not occurred within 16 hours, the suspension may safely be considered completely dispersed. When flocculation occurs during the test period, a "fluffy" sediment is observed at the base of the suspension, lighter in color than that of the layer of coarse silt that also accumulates.

It will be noted that no provision has been made in this plan for the removal of carbonates in the samples during the preliminary treatment. It is to be emphasized that when primary carbonate particles are present, they should be removed before the mechanical analysis is completed, because they are an integral part of the frequency distribution, and it would materially affect the data secured if they were first dissolved. That this effect is produced may readily be seen by considering the presence of arenaceous or argillaceous limestone fragments in the samples. Pretreatment with acid would disintegrate the grains and leave behind a residue of sand or clay which would load the smaller sizes at the expense of the larger, and thus result in an inaccurate picture of the sediment. When secondary carbonates occur, as in the cements of sandstones, they must of course be removed if the composition of the original sediment is desired. In cases where both primary and secondary carbonates are present, one can seldom be removed without also removing the other, and it is usually necessary to decide to remove either all

[9] Hahn, F.-V. von, *op. cit.*, p. 23.
[10] Gessner, H., *op. cit.*, p. 163.

or none before the analysis, depending upon the predominance of one or the other.

When it is certain that the sample is dispersed, the graduate containing the liter of suspension is well shaken and set at rest. The time is noted, and 1 minute 55 seconds later, 20 cc. are drawn into a pipette inserted exactly 10 cm. below the surface. The contents of the pipette are poured into a tared 50 cc. beaker, and evaporated to dryness on a hotplate having a temperature of about 100°C., so that the liquid does not boil or spatter. The weight of the residue is determined, a correction added for the amount of sodium carbonate present, and the result multiplied by 50, to obtain the total weight of material finer than 1/32 mm., in the sample. The suspension is in the meantime again shaken, and allowed to stand for 7 minutes 40 seconds. Another 20 cc. are drawn off as before, and the weight of material under 1/64 mm. determined. By subtracting the second from the first, the weight of the 1/32-1/64 mm. grade is found. The process is repeated at the intervals and the depths shown in the table until essentially all of the sample has been divided into grades.

The following example of the first several separations will indicate the routine: one liter of suspension contains 26.44 gm. of the sample, and 1.0 gm. sodium carbonate. The weight of the residue in the first beaker is 0.532 gm., and that in the second beaker is 0.446 gm. Since 1 gm. of sodium carbonate was used, each residue from 20 cc. of suspension contains 0.020 gm., and this amount is subtracted from the values found, leaving 0.512 gm., and 0.426 gm. These corrected values are multiplied by 50, giving 25.60 gm., and 20.30 gm. A table is set up as follows, which indicates the amounts of material in the successive grades:

Weight of material finer than 1/16 mm.	26.44 gm.
Weight of material finer than 1/32 mm.	25.60 (from first beaker)
Difference: amount in 1/16-1/32 mm. grade	0.84 gm.
Weight of material finer than 1/32 mm.	25.60 gm.
Weight of material finer than 1/64 mm.	20.30 (from second beaker)
Difference: amount in 1/32-1/64 mm. grade	5.30 gm.

These weights may be converted into percentages for frequency diagrams or cumulative curves, and if the sample contains material larger than 1/16 mm. it is sieved into grades in accordance with the method proposed by Wentworth.[11] The two parts of the analysis are then combined into a single table or curve for the entire sample.

COMPARISON WITH OLDER METHODS

In order to compare the results obtained by the pipette method with those obtained from one of the older routines, three samples of a clayey till were dispersed by the method described above, and allowed to stand for 16 hours to test for possible flocculation.

[11] Wentworth, C. K., Methods of mechanical analysis of sediments, *Univ. Iowa, Studies in Nat. Hist.*, vol. 11, no. 11, 1926.

COMPARISON OF PIPETTE AND SEDIMENTATION TUBE METHODS

Grades	Pipette: 1		Pipette: 2		Sedimentation Tube	
	Per cent	Cumulative Per cent	Per cent	Cumulative Per cent	Per cent	Cumulative Per cent
Above 1 mm.	3.4	3.4	3.3	3.3	4.0	4.0
1 –1/2	1.9	5.3	1.8	5.1	1.6	5.6
1/2 –1/4	2.3	7.6	2.3	7.4	2.3	7.9
1/4 –1/8	2.7	10.3	2.7	10.1	2.7	10.6
1/8 –1/16	2.5	12.8	2.5	12.6	2.4	13.0
1/16 –1/32	4.1	16.9	4.6	17.2	8.4	21.4
1/32 –1/64	6.5	23.4	7.2	24.4	18.6	40.0
1/64 –1/128	14.0	37.4	12.5	36.9	60.0*	100.0*
1/128–1/256	12.6	50.0	12.9	49.8		
1/256–1/1000	22.1	72.1	24.1	73.9		
Under 1/1000	27.9	100.0	26.1	100.0		

* The material below 1/64 mm. was grouped into a single size because of the difficulty of separating smaller grades.

Two of the samples were analyzed by the pipette method, and the third by a sedimentation method. In the latter method, the suspension was poured into a cylinder, and allowed to stand until all particles larger than 1/32 mm. could reach the bottom according to velocities computed by Stokes' law. The supernatant liquid was then siphoned off, and drained into another cylinder, to separate all particles larger than 1/64 mm. Fresh water, containing a concentration of sodium carbonate equal to that of the original suspension, was added six times to each cylinder, and the supernatant liquid was quite clear at the end of the sixth washing. The residue in the first cylinder was collected and dried, and sieved into grades as shown in the accompanying table.

The pipette analyses were run in the manner described in this paper, and in order to have some check on the analyses, concentrations of about 2.5 and 5 per cent were used, to allow for any effects of concentration on the final results. The data obtained are also shown in the table.

It will be noted that the amounts of material in the sieved grades agree very closely in all three analyses, while in the smaller sizes there is a marked divergence between the sedimentation and pipette methods. This divergence is even more marked when the data are plotted as cumulative curves, as shown in figure 1. The curve of the sedimentation method departs widely

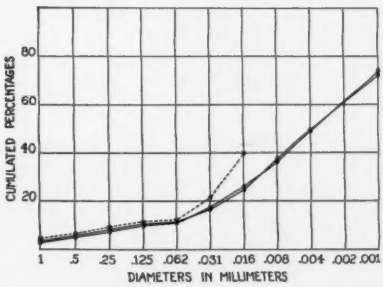


FIG. 1. Comparison of pipette and sedimentation tube methods on unaltered Wisconsin till. The solid lines represent the pipette analyses, and the broken line the sedimentation tube analysis.

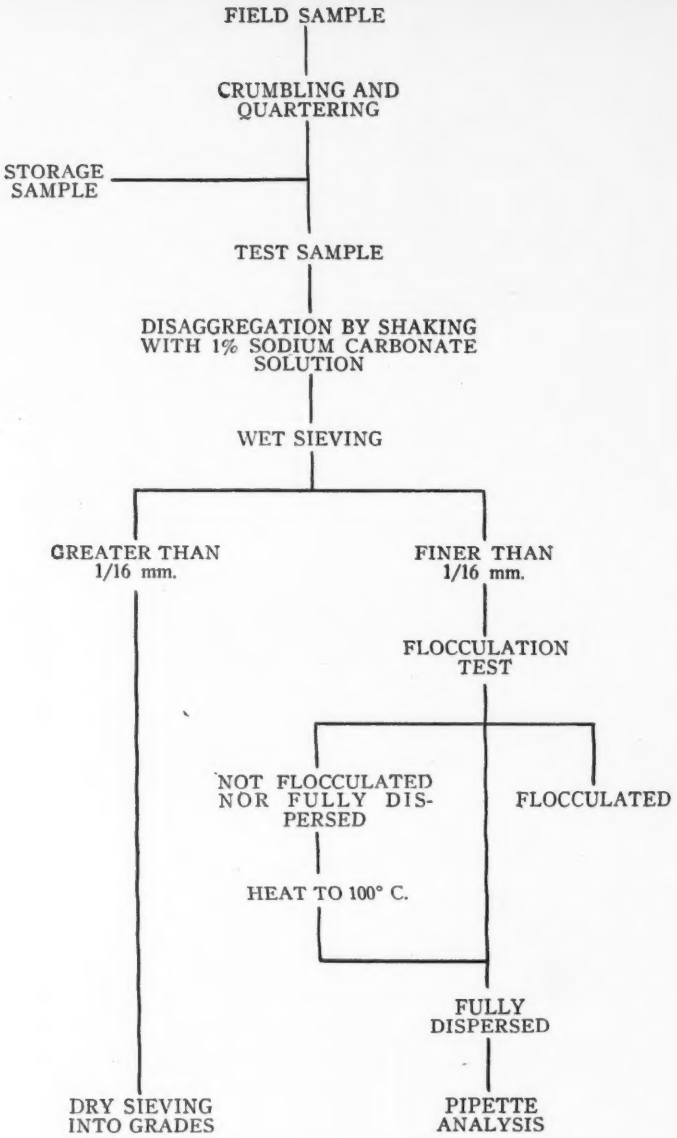


FIG. 2. Chart showing generalized routine of analysis.

from the pipette curves as soon as the sub-sieve sizes are reached. Attention is also called to the close parallelism of the two pipette analyses.

From these data it seems clear that the divergence of the upper curve from the other two is due to the fine material not separated from the two sedimented grades by the sedimentation method. If this is so, there is an error of more than 15 per cent in the analysis by the time the 1/64 mm. limit is reached. An error of this magnitude is sufficient to call into question the advisability of using such decantation methods for even approximate analyses.

SUMMARY

In order to summarize the steps involved in a pipette analysis, a flow sheet is shown in figure 2, which indicates them graphically. The steps involved include only those directly concerned with mechanical analysis, and do not include the determination of carbonates or the separation of heavy minerals, which may, however, be added to it if a more complete petrographic analysis is desired.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 2, NO. 3, PP. 150-159, TABLE 1, GRAPHS 1-3, PLS. 4-7, DECEMBER, 1932

SOURCE OF THE SANDS ON THE SOUTH SHORE OF LONG ISLAND AND THE COAST OF NEW JERSEY[1]

R. J. COLONY
Columbia University, New York City

In the summer of 1930 the writer was authorized to undertake a study of the sands on the Atlantic coasts of Long Island and New Jersey by the Board on Sand Movement and Beach Erosion of the War Department. The investigation was conducted with the object of ascertaining the source of the sands forming the beaches of both coasts. Samples of the sands were accordingly secured with the aid of Lieutenant L. H. Hewitt, Corps of Engineers, who was at that time stationed at Long Branch on special duty, under the direction of the Board.

The samples were selected between high and low water lines along the Long Island beaches from Montauk Point westward to Fort Hamilton, and along the New Jersey beaches from the tip of Sandy Hook to the Delaware River side of Cape May. In accordance with the wishes of the Board the intervals between the places where the samples were taken along the coast of New Jersey were shorter and a more intensive study was conducted of these samples than was the case of the samples secured along the beaches of Long Island. As it happened, however, this had no bearing on the results obtained, since the fewer samples taken along the beaches of Long Island were nevertheless sufficient to demonstrate the source of the material comprising the beaches of the South shore of Long Island.

Samples were taken from the following localities:

Long Island Shore

Station 69—Beach at Montauk Point
Station 68—Headland, Montauk Point
Station 67—Headland, Hither Plain, 10 miles east of East Hampton
Station 66—Beach, Hither Plain, 10 miles east of East Hampton
Station 65—Beach, East Hampton
Station 64—Beach, South Hampton
Station 63—Beach, West Hampton
Station 70—Beach, Fire Island
Station 62—Beach, Jones' Beach, Coast Guard Station
Station 61—Beach, Jones' Beach, Coast Guard Station, Zachs Inlet.
Station 60—Beach, Jones' Beach, New York State Park, Zachs Inlet.
Station 59—Beach, West End Long Beach, Point Lookout Coast Guard Station
Station 58—Beach, Long Beach
Station 57—Beach, Long Beach East Rockaway Inlet
Station 56—Beach, Rockaway Beach, South Arverne
Station 55—Beach, Rockaway Point

[1] This paper records some of the results of an investigation on the source of the beach sands of the New Jersey and Long Island Coasts for the United States Army Board on sand movement and beach erosion. Published by permission of The Beach Erosion Board, but the Board is not responsible for statements or conclusions contained in this article.

Long Island Shore (continued)

Station 54—Beach, West of end of Norton Point

Station 53—Beach, Fort Hamilton

New Jersey Shore

Station 50—Beach, Sandy Hook, U. S. Military Reservation

Station 49—Beach, Sandy Hook, Spermacetti Coast Guard Station

Station 48—Beach, Monmouth Beach, Coast Guard Station

Station 45—Beach, North Long Branch Foot Atlantic Avenue

Station 47—Headland, Long Branch, West End (representative sample)

Station 44—Beach, Long Branch, Coast Guard Station 101

Station 46—Headland, Deal (Material dubious, mixed)

Station 43—Beach, Loch Arbour, Coast Guard Station

Station 42—Beach, Shark River Inlet, North Shore

Station 41—Beach, Shark River Inlet, South Shore near stone jetty

Station 40—Beach, Bar across Wreck Pond, north side of opening

Station 39—Beach, Manasquan Inlet, North Shore

Station 38—Beach, Manasquan Inlet, South Shore

Station 37—Beach, Bay Head, Coast Guard Station 106

Station 36—Beach, Chadwicks, Coast Guard Station 108

Station 35—Beach, Toms River, Coast Guard Station 109

Station 34—Beach, Island Beach, Coast Guard Station 110

Station 52—Beach, ¼ mile south Cedar Creek Coast Guard Station

Station 51—Beach, Barnegat Inlet, North Shore

Station 33—Beach, Barnegat Point, South Shore, near light house

Station 32—Beach, Harvey Cedars Coast Guard Station

Station 31—Beach, Peahalla

Station 30—Beach, Point, north of Beach Haven

New Jersey Shore (continued)

Station 29—Inland, 1.4 miles from Tuckerton Creek, along road

Station 28—Beach, Brigantine Beach, Coast Guard Station 26

Station 27—Beach, Brigantine Beach, South end, across inlet

Station 26—Beach, Point, Atlantic City; Coast Guard Station

Station 25—Beach, Ventnor, ½ mile south Coast Guard Station

Station 24—Beach, Longport, South end of point

Station 23—Beach, Ocean City, North end

Station 22—Beach, Ocean City, Coast Guard Station

Station 21—Beach, Pecks Beach, Coast Guard Station

Station 20—Beach, Pecks Beach, Ocean City, south of pier

Station 19—Beach, Strathmere (recently made shore)

Station 18—Beach, Strathmere, foot of northernmost street

Station 17—Beach, Whale Beach

Station 3—Beach, Sea Isle City, foot 43rd street

Station 2—Beach, Sea Isle City, south end

Station 1—Beach, Townsends Inlet

Station 16—Beach, Avalon, on point, 8th St. and Avalon Ave.

Station 15—Beach, Peermont

Station 14—Beach, Holiday Beach

Station 13—Beach, North of Hereford Inlet, Coast Guard Station 132

Station 12—Beach, Wildwood, point

Station 11—Beach, North Wildwood

Station 10—Beach, Wildwood, Garfield Avenue

Station 9—Beach, Two miles north of Cold Spring jetty

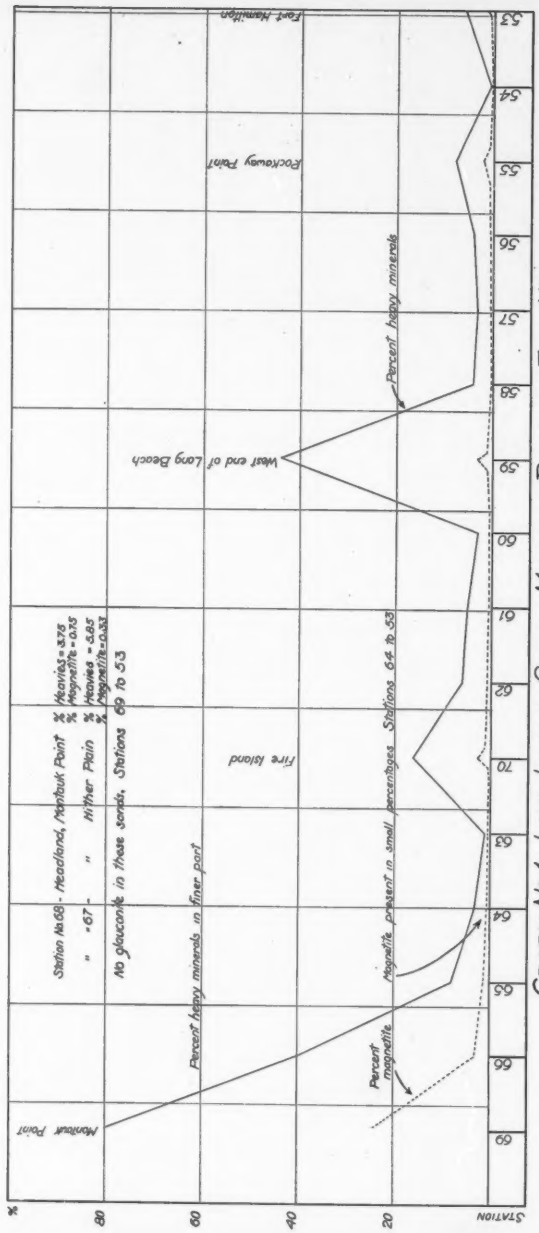
Station 8—Beach, North side of Cold Spring jetty

Station 7—Beach, Sewell's Point, ½ mile south of big jetty

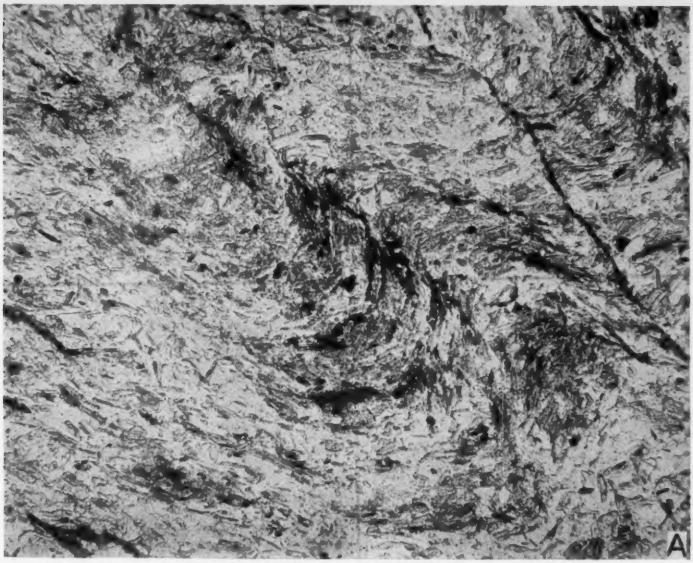
Station 6—Beach, Cape May City, near Congress Hall Hotel

Station 5—Beach, Cope May Point, ocean side

Station 4—Beach, Cape May Point, Delaware River side



GRAPH No.1. LONG ISLAND COAST—MONTAUK POINT TO FORT HAMILTON



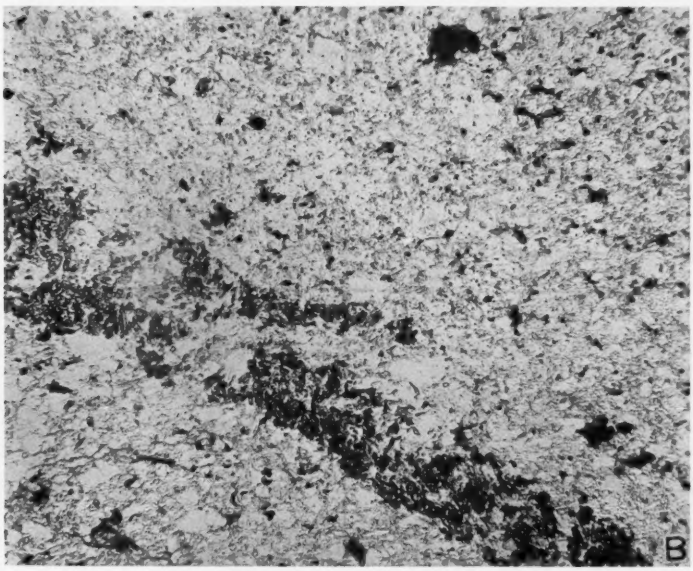


PLATE 4

TYPICAL PEBBLES FROM THE SOUTH SHORE OF LONG ISLAND

A. Pebble from beach at South Hampton, Long Island, Station 64. Ordinary light, ×72. A fine-textured, crumpled, quartz-sericite-chlorite phyllite, from the complex metamorphic upland of New England. The darker gray portions shown in the picture are chlorite, the slightly lighter scales and needles are sericite and the light-gray smooth groundmass is a finely crystalline aggregate of quartz.

B. Pebble from beach at East Hampton, Long Island, Station 65. Ordinary light, ×30. A fine-textured metamorphic quartzite, with considerable intermixed sericite and epidote. The dark band extending diagonally across the picture is a band of epidote crystals. From the New England upland.

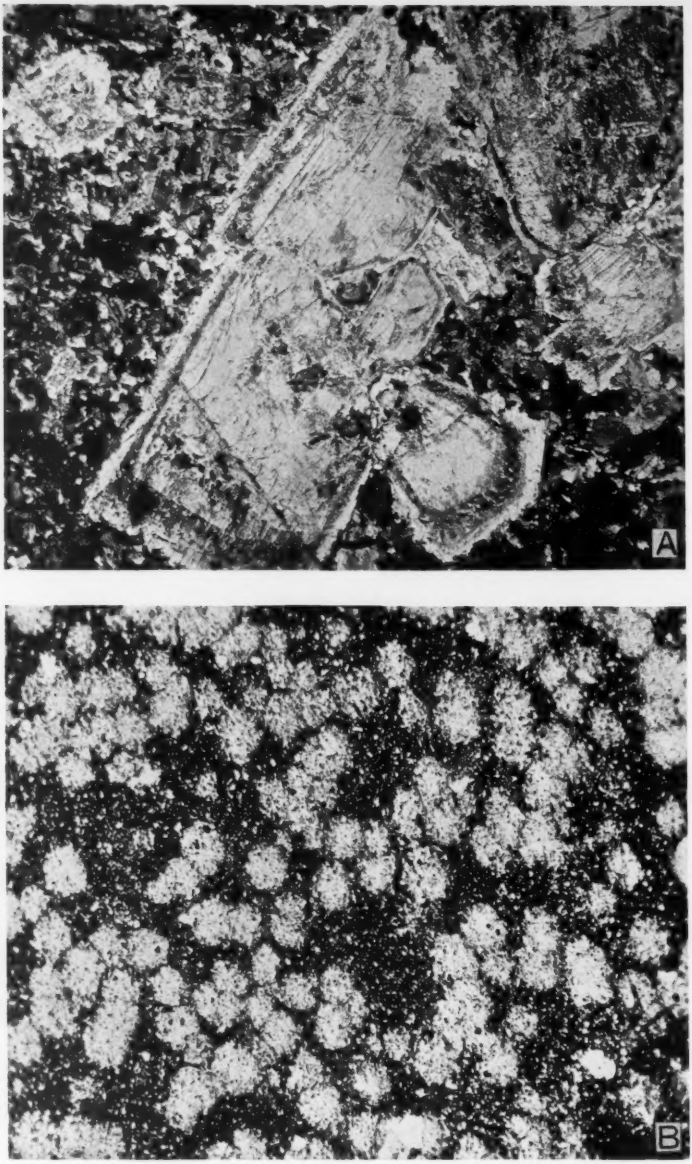
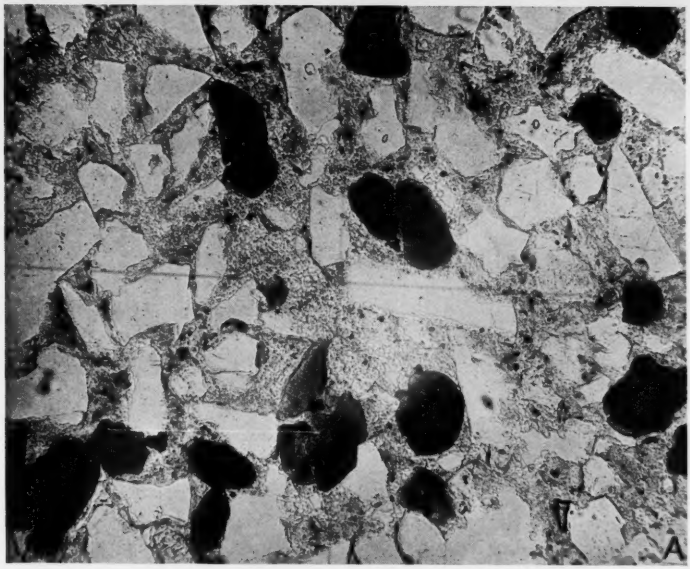


PLATE 5

TYPICAL PEBBLES FROM THE SOUTH SHORE OF LONG ISLAND

A. Pebble from beach at Fort Hamilton, Long Island, Station 53. Nicols crossed, ×25. A strongly porphyritic igneous rock of quartz monzonite type. The large phenocrysts are moderately basic, beautifully zoned plagioclase feldspar. The fine granular groundmass is a mixture of quartz, alkali feldspar and biotite, with a little acid plagioclase. Derived from the crystalline complex to the north.

B. Pebble from beach at Fort Hamilton, Long Island, Station, 53. Ordinary light, ×30. An original shale, metamorphosed by contact processes, with the development of reorganization substances in finely crystalline, erratically distributed spotty areas. A spotted hornfels, probably representing material from the contact zone under the base of the Palisades diabase.



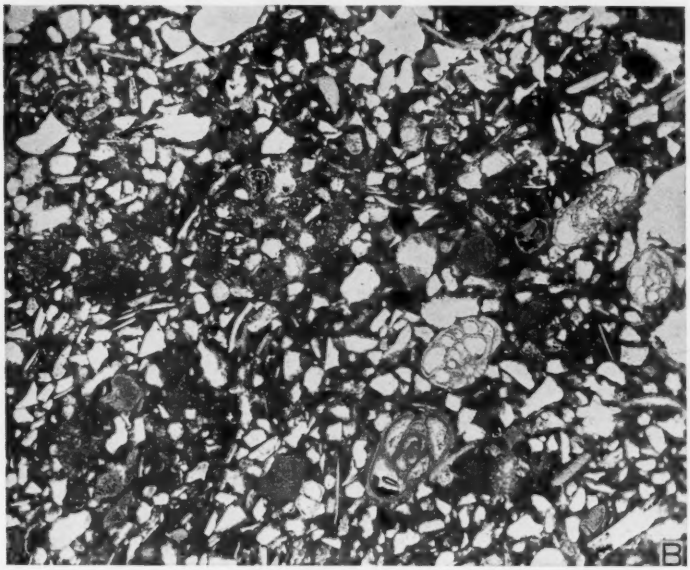


PLATE 6

TYPICAL PEBBLES FROM THE SANDS OF THE NEW JERSEY COAST

A. Pebble from Monmouth Beach, New Jersey, Station 48. Ordinary light, ×72. A cherty grit carrying glauconite (the very dark grains). The angular, white grains are quartz and the fine groundmass is composed of finely crystalline silica, comprising the chert. Derived from the Coastal plain sediments of New Jersey.

B. Pebble from beach at Shark River Inlet, New Jersey, Station 42. Ordinary light, ×30. A fine, glauconitic, foraminiferal and quartzose marl. All the white angular grains are quartz. The dark, exceedingly fine groundmass is composed of a mixture of argillaceous matter, and very fine carbonate.

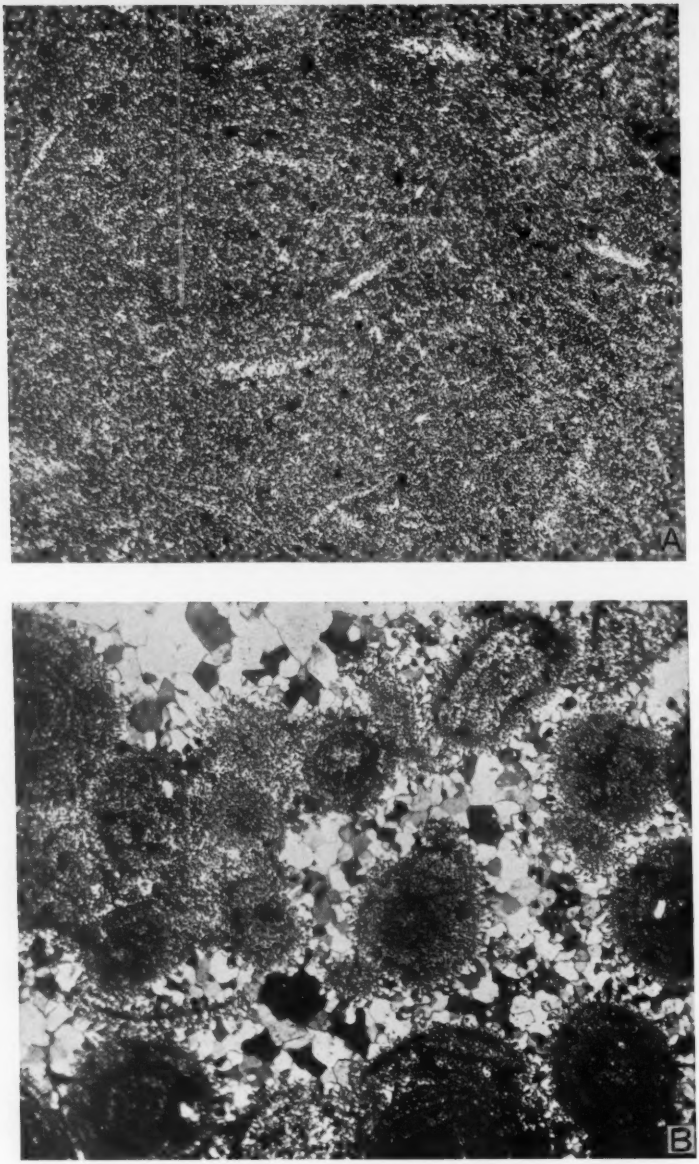


PLATE 7

TYPICAL PEBBLES FROM THE SANDS OF THE NEW JERSEY COAST

A. Pebble from beach at Strathmere, New Jersey, Station 19. Nicols crossed, ×80. Chert pebble. Note the characteristic, finely crystalline, siliceous character of the pebble. The lighter colored, straight streaks are silicified or "de-colloidalized" spicules. A fossiliferous chert pebble from the Coastal plain sediments.

B. Pebble from beach on the Delaware River side of Cape May, New Jersey, Station 4. Nicols crossed, ×70. A silicified, cherty oolite, probably carried down by the river. from an up-stream source.

All the samples collected were washed with water and treated with dilute hydrochloric acid in order to remove soluble sea-salts and shell fragments, and the cleaned and dried samples were weighed and passed through a set of standard screens. Suitable weights of the material passing the 60 mesh screen were separated into light and heavy fractions with tetrabromoethane, specific gravity 2.9. The larger part of the heavy minerals passed the 60 mesh screen, and the material so obtained could be conveniently handled in the liquid used for separations. The glauconite found in the New Jersey sands was however in general coarser than 60 mesh, and floated with the quartz and feldspar in the separating liquid used. Magnetite was then removed from the heavy fractions by magnetic separation, and the magnetite-free heavy residues, and the lighter portions as well, were then studied petrographically.

In numerous localities beach pebbles are mixed with the sands. These were studied separately; many of the pebbles are quartz pebbles, which required only superficial examination. Others are much more complex; from such pebbles numerous thin sections were made, in order to facilitate the proper classification of them and as an aid to interpretation.

The material studied consisted therefore of:

(*a*) Samples of the headlands and certain inland samples
(*b*) Samples of the beach pebbles
(*c*) Light fractions of the beach sands
(*d*) Heavy fractions of the beach sands

The light fractions of the sands were studied in suitable immersion media; the heavy fractions were likewise studied in immersion media, and in addition some of the heavy fractions were mixed, made into pats with Portland cement in the proportion of 3 to 1, and thin sections were made from the pats.

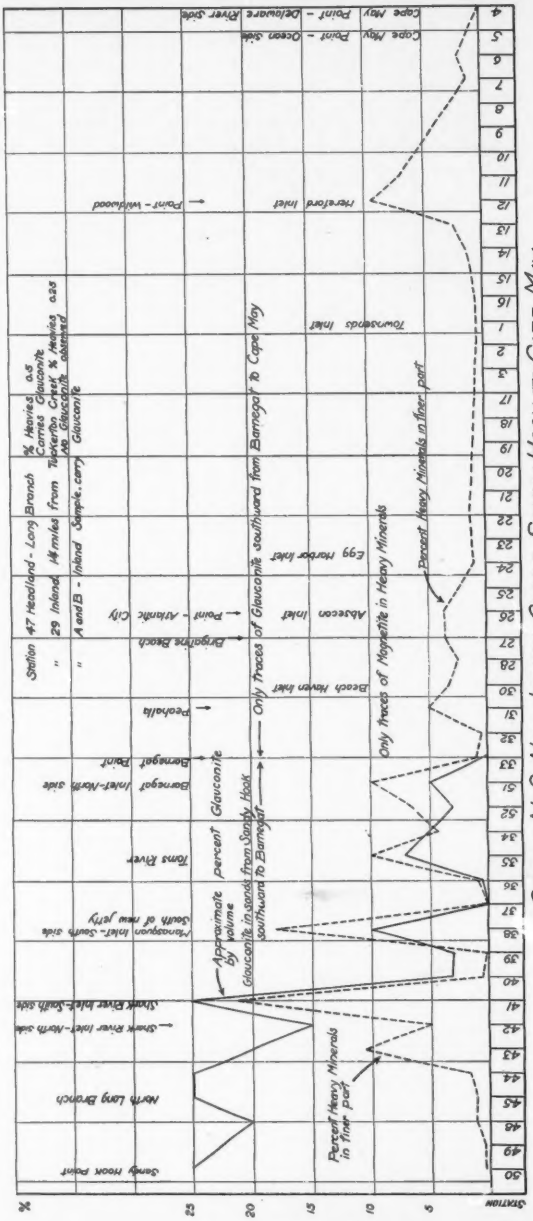
This method permits an accurate check on the grains examined in immersion media.

GENERAL GEOLOGIC SETTING

Long Island. The surficial geology of Long Island is essentially wholly glacial. The terminal moraine of the Wisconsin ice-sheet extends along the Island in an east-west direction, but only at the extreme eastern end of Long Island does the terminal moraine form part of the south shore. From a point a few miles west of Hither Plain easterly to Montauk Point the terminal moraine is itself the shore.

The moraine is composed of a mixed complex containing gravel and boulders, derived from the crystalline rocks of the New England upland, which the ice picked up and carried along and ultimately dumped at its frontal margin. The moraine, composed of material secured by the ice from the crystalline rocks of New England, is truncated by the Atlantic Ocean within the distance along the south shore mentioned above.

The frontal edge of the terminal moraine swings westerly away from the shore line in the neighborhood of Promised Land, thence trending away from the coast westerly along the entire remaining length of the Island. The immediate hinterland of the shore from



GRAPH No. 2. NEW JERSEY COAST-SANDY HOOK TO CAPE MAY

Promised Land westward consists of more or less sandy outwash material from the moraine; there are neither Tertiary nor Cretaceous deposits exposed to attack by the ocean on the Atlantic shore of the Island.

The sand forming the beaches of the south shore of Long Island should therefore partake of the character of the moraine and its outwash plain unless the beach sands were derived from a source totally foreign to and unrelated to the Island.

New Jersey. The geology of the coast hinterland of New Jersey is quite different from the geology of Long Island. No glacial drift exists along the New Jersey coast. The formations are older; they consist of Cretaceous and Tertiary sediments which were derived themselves from a different source distant from the ancient crystalline rocks of New England. Cretaceous sediments, carrying considerable glauconite, constitute the shore from the base (southern part) of Sandy Hook southward as far as Monmouth Beach, at which point they give way to Tertiary and post-Tertiary sediments which continue southward to Cape May.

The sands along the beaches of New Jersey should likewise reflect the character of the materials of their source; and provided the source of these sands is the substance that constitutes the older coastal plain sediments, the beach sands should carry some evidence of that connection. All of the samples were studied with these geologic facts in mind.

Another feature of some importance is the configuration of the shore line. Where inlets are located local concentration of the heavier minerals, or of some strikingly different component of the lighter minerals may occur, owing to tidal currents which are more or less active in such places.

MINERALS IN THE SANDS

The minerals in the sands are listed in the table. The list is undoubtedly not complete; the minerals included in the list are those that are more or less persistent in all of the samples taken, including a few of questionable identity, so indicated in the table. No attempt has been made to determine actual percentages of the various individual minerals in the samples, with the exception of the total heavies, the magnetite in the heavies and the glauconite, the percentages of which in the finer parts of the sands have been approximately estimated. Although many of the minerals occur both in the sands of Long Island and New Jersey, some of them appear in greater proportions in the sands of one coast than in the sands of the other. Thus, for example, feldspar and garnet are more plentiful in the sands of Long Island than in the sands of New Jersey, and both occur in larger percentages in the beaches on the east end of Long Island than in the beaches on the west end of Long Island.

The presence of certain minerals in the beach sands of one coast and their absence in the beaches of the other, and the differences in the characters of the same group of minerals in the sands of one coast as compared with the other, are taken to be diagnostic. Minerals occurring exclusively in the sands of one coast, not appearing in the sands

of the other, are indicated in the table by black circles. Minerals not observed in the sands of one coast and not of the other are designated by circles in outline only, and minerals common to the sands of both coasts are indicated by circles containing crosses.

DIAGNOSTIC MINERALS

There are uniformly higher percentages of heavy minerals in the sands of the south shore of Long Island than in the sands of the New Jersey beaches.

Table of minerals in sands.

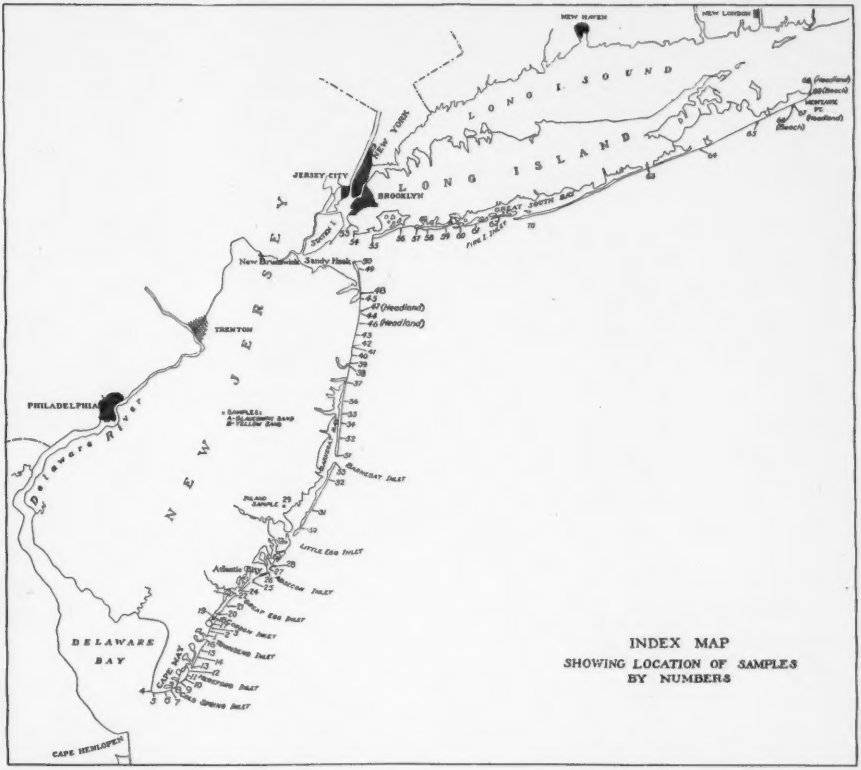
	Long Island	New Jersey		Long Island	New Jersey
Actinolite	⊕	⊕	Ilmenite	⊕	⊕
*Analcite	○	●	Leucoxene	⊕	⊕
*Andalusite	○	●	*Magnetite	●	○
Arfvedsonite	⊕	⊕	*Mica (green)	●	○
Biotite	⊕	⊕	*Muscovite	○	●
*Chlorite	○	●	Pyroxene	⊕	⊕
*Chloritoid	○	●	Quartz	⊕	⊕
*Cordierite	○	●	Rutile	⊕	⊕
*Cyanite	●	○	*Spinel (blue)	●	○
Diopside	⊕	⊕	Staurolite	⊕	⊕
Epidote	⊕	⊕	Titanite	⊕	⊕
Feldspars (various)	⊕	⊕	*Tourmaline (green-brown)	○	●
Fibrolite	⊕	⊕	*Tourmaline (mahogany)	○	●
Garnet (colorless)	⊕	⊕	*Tourmaline (lilac-blue)	●	○
Garnet (pink)	⊕	⊕	Tremolite	⊕	⊕
*Glauconite	○	●	Vesuvianite (?)	?	⊕
Hornblende (brown)	⊕	⊕	Wollastonite (?)	?	⊕
Hornblende (green)	⊕	⊕	Zircon	⊕	⊕
Hypersthene	⊕	⊕	Zoisite (?)	?	⊕

*● Diagnostic minerals ⊕ Minerals present in sands ○ Minerals absent in sands

Table showing mineral occurrences in sands.

This is strikingly shown in the sands composing the beaches of eastern Long Island, between East Hampton and Montauk Point. The *finer* portions of the beach sand at Montauk Point contain 80 per cent of heavy minerals; of these magnetite is present to the extent of approximately 25 per cent, and ilmenite and garnet are dominant in the remainder. The amounts of heavy minerals decrease sharply, however, from Montauk Point westward to West Hampton, falling to approximately one per cent at the latter place, increasing abruptly, however, wherever inlets occur, as shown by the distribution curves. While magnetite is present in the sands of all the Long Island beaches, the amount is very small from West Hampton westward. There is no magnetite at all in the beach sands of New Jersey, except in dubious traces in one or two instances in the vicinity of some of the jetties, which are made of blocks of pre-Cambrian crystallines from the Highland areas from which the very dubious traces mentioned may have been derived. No glauconite whatever occurs in the beach sands of Long Island. Glauconite occurs however in the sands of the New Jersey beaches, reaching maximum percentages in the sands of Sandy Hook, especially at the point, decreasing in quantity southward to Barnegat point, but with abrupt increases in quantity where the various inlets occur, in common with the behavior of the heavy minerals in these sands.

From Barnegat Point southward only occasional traces of glauconite were observed. Moreover, ilmenite takes the place of magnetite in the sands of the entire New Jersey coast. Cyanite, green mica, blue spinel, and a lilac-blue tourmaline occur in the sands of the south shore of Long Island, but were not observed in the sands along the New Jersey shore. Andalusite, cordierite, chloritoid, muscovite, zoisite (?), and both green-brown and mahogany-colored tourmaline were found in the New Jersey sands, but these minerals were not detected in the Long Island sands. The presence of certain groups



of minerals mentioned above in the sands of one coast and the absence of certain groups in the sands of the beaches of the other coast is judged to be diagnostic of different sources of supply.

BEACH PEBBLES

With the exception of ubiquitous pebbles of quartz, the beach pebbles themselves serve as indicators of source. Thus, excepting quartz, the beach pebbles distributed along the south shore of Long Island consist of metamorphic and igneous rock. Among them were observed pebbles of gneiss, mica schist, phyllite, hornfels, hornblende schist, granite, pegmatite and quartzite. No chert pebbles were encountered in the beach sands of Long Island with the exception of the beach at Fort Hamilton. The material composing this beach is unique and much mixed, since here the source is a "mixed" source, owing to the situation. Fort Hamilton lies on the extreme west end of the Island, opposite Staten Island and just south of the confluence of the Hudson River and

East River. Consequently the beach sands contain a great variety of pebbles that are indicative of several sources. Among them were observed pebbles of schist, gneiss, granodiorite, pegmatite, granite, spotted hornfels, red, light brown and gray sandstone that may have been derived from the Triassic sediments of New Jersey; black and banded chert, as well as material contributed by man in the form of rolled pieces of brick, rolled bottle glass, coal and other detritus.

Some of the characteristic pebbles distributed along both coasts are illustrated by photomicrographs. The striking thing in connection with them is the absence, along the coast of New Jersey, of pebbles derived from the complex igneous and metamorphic terrane of New England.

No such pebbles were found in the sands of the New Jersey beaches, which contain instead pebbles consisting dominantly of quartz of various colors and kinds, chert pebbles in variety, many of them carrying spicules; glauconitic cherts and marls, fossiliferous pebbles, sandstone pebbles, silicified pebbles of oolite and occasional mudballs.

In brief, both the sand and the beach pebbles on the south shore of Long Island were derived from the terminal moraine of the Wisconsin ice sheet and from its outwash plain. The material of the terminal moraine itself was secured by the glaciation of the crystalline complex of the New England upland; the débris was transported by the ice and dumped along its frontal margin. Whereas the sand and pebbles along the New Jersey Coast were derived from the sediments of the Coastal plain of New Jersey, and the heavy minerals in those sands came from a source twice removed. That is, the heavy minerals in the sands of the New Jersey beaches represent reworked heavy detrital matter from the Coastal plain sediments, derived initially from the Appalachian region, and hence, so far as the occurrence of it in the present-day beaches is concerned, twice removed from the original source.

THE DISTRIBUTION CURVES

The distribution of the heavy minerals and of the magnetite forming part of the heavy minerals in the sands along the South Shore of Long Island is shown in Graph 1. The amounts of heavy minerals are relatively large in the beach sands from Montauk Point to East Hampton, as shown by the distribution curve. West of East Hampton the percentages of heavies are much lower, except locally, as shown by peaks in the curve.

Thus there is concentration of the heavy minerals at Fire Island (station 70), at Rockaway Point (station 55), and at Fort Hamilton (station 53). There are inlets at all of these places and presumably local concentration of the heavies is due to the action of tidal currents.

Graph 2 shows the distribution of both heavy minerals and of glauconite in the beach sands of New Jersey. The peaks in the curves are quite strikingly connected with the stations at the various inlets. Moreover, both heavy minerals and glauconite are locally concentrated in the same places along the coast; the peaks in the distribution curve for glauconite accord with the

peaks in the heavy mineral curve. Such local concentration of both glauconite and of heavy minerals in the vicinity of the inlets is judged to be due, as before stated, to the action of tidal currents which wash out the finer, lighter material and thus concentrate the heavier and the coarser detritus. The larger percentages of glauconite occur in the sands of the beaches between Sandy Hook Point and Shark River inlet. South of this inlet the amount of glauconite is much less, although there is some concentration at the inlets between Shark River and Barnegat. South of Barnegat only the merest traces of glauconite were observed in the sands.

GENERAL CONCLUSIONS

(1) Since the sands of the ocean beaches of Long Island are composed of materials obviously derived from the terminal moraine of the Wisconsin ice-sheet and its outwash plain, the immediate source of those sands is the moraine and its associated outwash plain. The *ultimate* source is the complex, crystalline metamorphic area to the north that forms the New England upland, from which the ice-sheet secured its load of glacial débris.

(2) The decreasing amounts of the heavy components in these sands from Montauk Point westward indicate a westward movement of the sand along the south shore of Long Island. Local concentration of the heavy components at or in the vicinity of inlets, shown by peaks on the distribution curve, is judged to be due to the action of tidal currents.

(3) The material comprising the beach at Fort Hamilton is mixed because of the situation and environments. The source is a "mixed source."

(4) The sands composing the beaches of New Jersey have little in common with the beach sands of Long Island except quartz and feldspar. Their composition in terms of significant minerals is quite different because the source is different. These sands do not originate from the glacial débris of a former ice-sheet. The significant minerals in them are common to the coastal plain sediments of New Jersey; hence the Cretaceous and Tertiary sediments comprising the coastal plain represent the immediate source of these sands.

(5) From the distribution and quantity of glauconite in the New Jersey beach sands from Monmouth Beach northward to Sandy Hook, and because glauconite-bearing Cretaceous sediments are truncated by the ocean within the limits of the area mentioned, it is judged that the movement of the sands is northward from Monmouth Beach to Sandy Hook. From Monmouth Beach to Cape May the sand in general moves southward.

Peaks in the distribution curve of both heavy components and of glauconite are judged to indicate local concentration of these components owing to the action of tidal currents. In both graphs the peaks in the curves correspond to the locations of inlets along the coasts.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 2, NO. 3, PP. 160-161, FIGS. A, B, C,
DECEMBER, 1932

A SIMPLE DEVICE FOR THE MANIPULATION OF INDIVIDUAL DETRITAL GRAINS OF MINUTE SIZE

ARTHUR D. HOWARD
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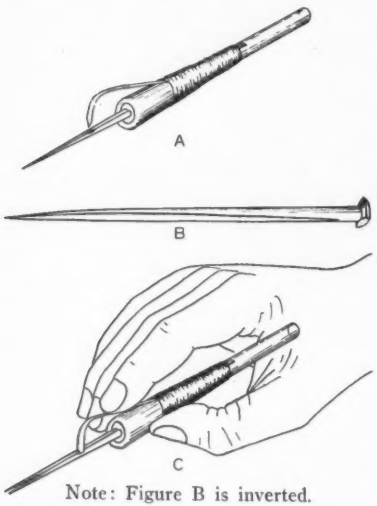
In dealing with sediments it often becomes necessary to manipulate individual detrital grains of minute size. Such necessity arises, for example, when the indices of refraction of a mineral of uncertain identity are to be determined by immersion in various index liquids. Occasionally in transferring the mineral fragment from one liquid to another the particle is lost, and provided it is the only one of its species in the sediment its loss is keenly felt. The author feels that much of the difficulty is due to the lack of a simple appliance for the safe and easy handling of such minute grains. Experimentation along this line has led to the construction of the instrument described in this article and illustrated in Fig. A. This simple, though admittedly crude appliance, is advantageous in having its pincers normally closed; they must be forced apart to receive a mineral grain. Once the particle is caught between the two jaws the instrument can be handled freely with the assurance that the particle cannot fall out. This is in contrast to most pincers in which the jaws must be held together as long as they are to retain an object in their grasp. With this latter type a moment's relaxation allows the pincers to open and the object is lost. Even when the fragment is later found the time wasted in searching for it is a disturbing factor.



Note: Figure B is inverted.

The following materials are needed in the construction of the instrument:

Two plain brass pins about an inch and three quarters in length.
Four and a half inches of glass tubing with an inside diameter of 0.4 cm.
Four inches of flat wire about one-sixteenth of an inch wide. The wire should be only moderately elastic.
Several rubber bands.
A cork "grip" from an ordinary penholder.
A common bottle cork.
A fine file.
A bunsen burner.
A small vise.

Fasten each of the pins in turn in the vise and on each file a flat surface which cuts diagonally across the length of the pin so that it "bisects the point" but tapers out toward the head (Fig. B). On each of these bevelled surfaces, about halfway between the point and head of the pin, file a shallow notch so that when the two pins are placed lengthwise together with the flat surfaces inward, the two notches will come together to form an opening. The next step is to fasten these pincers into a holder—the glass tubing. First fasten the pincers firmly into the bottle cork, points foremost. This will keep the pins in position while they are being "welded" into the glass tubing, and will also enable the operator to hold them when they have become hot. The headward end of the pincers is now inserted about an eighth of an inch into the hollow end of the glass tubing. The "welding" process merely involves fusing the end of the glass tubing to imprison the pincers. In order that the tubing retain its shape during the fusion it is advisable to rotate both it and the pincers as the operation proceeds. Now fit the small cork "grip" over the fused end of the glass tubing so that it occupies the same position here as it did on the penholder. It furnishes a place where the instrument can be gripped, and offers partial anchorage for the appliance whereby the jaws of the pincers are opened. The mechanism for opening the jaws is constructed from the four-inch length of flat wire. Bend the wire in the middle so as to form a broad shallow "V." The angle between the arms should approximate 165°. File a moderately sharp point on one end of the wire. Starting about three-quarters of an inch above this point bend the wire downward—that is, in a direction opposite to the first bending—so that the bent portion makes a rounded angle of slightly over 90° with the remainder of the arm of the "V" (Fig. A). Adjust the wire on the instrument so that the sharpened end hovers directly above the opening between the jaws of the pincers while the other end of the wire lies flat along the holder. Fasten this straight portion of the wire firmly to the holder with rubber bands.

The instrument is held like a pen with the index finger resting lightly on the portion of the wire which rises from the holder. To open the jaws of the pincers press down on the wire so as to force its sharpened end into the opening (Fig. C). Very little pressure is needed to wedge the jaws apart. Raising the finger permits the jaws to close. A particle gripped in the jaws of this instrument can be released only by again deliberately wedging the jaws apart.

With the aid of these pincers the author has handled successfully, and with ease, mineral particles less than 0.1 mm in size. Its ease and delicacy of manipulation, plus its simplicity of construction, recommend it for trial in sedimentation laboratories. The device has been well tested by the author.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 2, NO. 3, PP. 162-166,
DECEMBER, 1932

INORGANIC MARINE LIMESTONE

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For many years there has been a conjecture that bacterial activity plays a part in the formation of many limestones. Evidence has been advanced by some which indicates that the hypothesis may be tenable with respect to certain specific localities. Others maintain that any serious entertainment of the proposal is an extravagance. The suggestion has evolved gradually and has been modified from time to time. Oceanographers and geologists have long recognized that the gradual addition of ammonia to sea water will cause the precipitation of calcium carbonate. Assuming that the decomposition of organic matter in the ocean would produce ammonia, they also believed that calcium carbonate might be precipitated from the sea water as a result of such decomposition. Sir John Murray pointed out that the accumulation of calcium carbonate sediments is greater in the warmer than in the cooler parts of the oceans.

Some thirty years ago an explanation was sought by Brandt for the relatively small production of phytoplankton in tropical seas. He suggested that the nitrate relations of the warmer water were disturbed by accelerated activity of denitrifying bacteria, and that available plant nutrient was thereby reduced. This suggestion aroused the interest of Drew, who started a field study of Brandt's denitrifiers in the Bahamian and Floridian regions. Among his observations was that of the production of ammonia by bacteria of this area.

Vaughan was at that time engaged on a study of the calcium carbonate bottom deposits of the locality. He suggested to Drew that this bacterially-produced ammonia might be responsible for the precipitation of calcium carbonate in the vicinity of the Florida Keys and the Bahamas. Ammonifying bacteria were definitely discussed as factors in the laying down of the deposits.

Investigators have since combed over the Bahama Islands and those of the Tortugas group at the tip of the Florida reef. This coral area is still a favorable one for both field and experimental examination of the theory. Comparisons are possible between open ocean water and that of sheltered lagoons. Sediments are accumulating at the present time in shallow and deep water, and there are many good exposures of Tertiary and Quaternary limestones.

Successive publications on the problem have brought forward facts which do not invalidate the conclusion that in this particular area at least, the bacteria may be accessory factors. On the other hand, the position has been

taken that even in this limited zone, the process is essentially chemical. Little has been definitely proven to the satisfaction of all concerned. Bacteria have been isolated, especially from sheltered places. Precipitates of calcium carbonate have been produced in experiments of varying significance. The inferences have usually outrun the established facts. This circumstance may explain the polemics which have centered about data which are not necessarily diametrically opposed.

The discussion was revived in *Science* a year ago by the exchange of almost contentious notes between Bavendamm[1] and Lipman.[2]

In 1928, Dr. T. Wayland Vaughan, director of the Scripps Institution of Oceanography, drew this long-standing controversy to the attention of the writer, then bacteriologist of that department of the University of California. A study of the problem was undertaken at La Jolla along fundamental lines, which has yielded certain definite, though by no means comprehensive, results. In 1930 the writer had an opportunity to conduct field work at Tortugas through the interest and generosity of the Carnegie Institution of Washington.

Progress reports on this work have appeared from time to time in the Reports for 1928-29 and 1929-30 of the Committee on Sedimentation, Division of Geology and Geography, National Research Council; in the Year Book of the Carnegie Institution of Washington for 1930, and in other publications.

[1] Werner Bavendamm, *Science* 73, 597-8 (1931).
[2] Charles B. Lipman, *Science* 74, 150-1 (1931).

In view of recurrent discussion of the matter in many journals, and of the possible interest of some of the recent findings to those outside the oceanographic field, a brief preview of the new results may not be out of place here.

The research will be described in detail in the appropriate journals in a group of nine papers, under joint authorship where others collaborated on various phases of the problem.

Chemical aspects are considered in six sections under the general title "Calcium equilibrium in sea water," to appear as a technical bulletin of the Scripps Institution. In the first of these papers, the known pertinent biological, geological and analytical facts about the sea are introduced in physico-chemical calculations. No evidence is found for the common supposition that sea water generally contains many times as much dissolved calcium as should remain in equilibrium with it. It is concluded that in temperate latitudes the water should be near the balancing point with respect to solid calcium carbonate, and that in tropical shallow water the chemical conditions may favor the separation of a small fraction of the calcium as carbonate.

In the second paper with David M. Greenberg and Erik G. Moberg, this theoretical conclusion is put to the test on sea water samples held in thermostats with solid calcium carbonate, under conditions approximately the same as those of the ocean in subtropical latitudes. No rapid or significant loss or gain of dissolved calcium was observed.

The third paper with Erik G. Moberg, deals especially with the gas

phase as one of the controlling factors in the equilibrium. Experiments in an aeration tower apparatus show that a reduction of the total carbon dioxide of the water can cause a definite loss of analyzable calcium under the conditions in low latitudes. Increasing the CO_2 of the water reverses the process.

The sluggishness of the equilibrium in responding to even wide variations in the chemical factors necessitated observation of samples for periods of weeks. There was a suspicion that biological activity over this interval was introducing an additional and undesirable complication. The fourth paper describes a glass apparatus for aseptic aeration of the water samples, which can be sterilized throughout, filled with the sample by means of a Berkefeld filter, and maintained without indication of any biological activity for an indefinite time.

Results under bacteriological control and with successive chemical analyses on water in this apparatus are detailed in the fifth section of the series. It is shown that removal of CO_2 under aseptic conditions causes a 4 per cent loss of calcium at tropical temperatures. This appears as crystalline calcium carbonate. It is shown also that, despite violent agitation, the sample may remain in an unstable condition for weeks, apparently supersaturated, but losing only water.

The crystals obtained in this way are described in a final paper by Roger R. Revelle, who finds them identical in form, size and optical properties, with naturally occurring needles of aragonite from a well-known deposit of calcareous mud in the Bahamas.

Two bacteriological papers of the group are scheduled for Publication No. 435 of the Carnegie Institution, under the title "Lime deposition and the bacteria." They deal essentially with local conditions at the Florida Keys. The first records a collection of aerobic bacteria from the sea water and lime mud of this region. It reports the mud itself to be highly reducing, although possible anaerobes were not given special attention at the time.

The second bacterial paper, with Catharine B. Feltham, classifies as *Pseudomonas* the common aerobes encountered in the work, without specific designation. It emphasizes the morphological variability of the bacteria, a property common to water organisms. Ammonia is produced uniformly. Carbon dioxide or acids could not be found among the products of metabolism. Their chemical behavior, therefore, fixes the organisms described as possible accessories in calcium carbonate precipitation.

An incidental paper in the group will be published in the *Journal of Bacteriology* under the title "Filtration technic." It describes a method for preserving unmodified sea water indefinitely against chemical alteration due to biological activity. The storage of sea water for chemical or biological purposes has usually been accompanied heretofore by some spontaneous precipitation. The appliance may find incidental use in serology, for handling filtrates.

The following comment may be made here on the differences of opinion between Bavendamm and Lipman:

(1) Bavendamm is supported in the view that the evidence for significant bacterial precipitation is strongest in

certain sheltered areas, as in mangrove swamps.

(2) Lipman is supported in the claim that no case has been made as yet for wholesale and high seas precipitation through the agency of bacteria.

(3) Bavendamm's relegation of physico-chemical factors to second place is dangerous. Carbon dioxide occupies a central position as a controlling factor in the equilibrium. It must be given equal consideration with ammonia as a possible product of bacterial metabolism. The biological and the chemical aspects of this geological problem can therefore not be considered as distinct from one another.

(4) Lipman's earlier conclusion, that certain apparently bacterial precipitates were really the result of calcium added along with nutrient material, is not necessarily valid. It is not essential to add anything to normal sea water in order to cause the separation of calcium carbonate. It is now shown that aragonite needles can be produced at ordinary temperature without any primary change in the water other than the loss of CO_2.

The present group of papers thus takes a middle position. The investigation is not so far advanced as to leave no scope for differences of interpretation. The known facts, however, including the additional results presented here, are in essential agreement.

It is believed that with the methods and apparatus outlined, the general chemical picture can be completed in a direct empirical way, and without recourse to incomplete theory. Continuation of the biological side of the story in specific localities might include consideration of the rate of CO_2 consumption by algae, a possible factor in precipitation. A quantitative study of sulphur bacteria as they may occur in the reducing mud is essential.

The sulphur organisms, with endocellular calcareous granules, are the only bacteria to which the phrase "specific precipitating power" applies. The influence of others, including the aerobic *Pseudomonas*, is possibly accessory, but if so is also indirect.

Local consideration might well be given to the possible place of guano in the scheme. On Bird Key in the Tortugas group, nitrogenous compounds are present in sufficient amounts to cause a pronounced odor of ammonia all over the island. The chemical factor of dissolved ammonia should therefore be appraised, not by taking the average determined value for sea water, but by determining the amount actually present in the area where the calcareous mud occurs.

Lastly, the successful production of aragonite from sea water suggests a problem of petrologic interest. Additional needles have recently been obtained by Fleming and Revelle by removing CO_2 from La Jolla water samples at 30°. The research thus appears to have as a by-product a promising recipe for "synthetic" aragonite. Other preparations given in the literature for this crystal form require constant attention, or are likely to yield an admixture of calcite.

It will be useful to know whether the artificial material contains the same small but constant amount of sulphate which is found in the natural aragonite needles from the Bahamas deposits. The conditions which favor the appear-

ance of aragonite instead of calcite during the crystallization of calcium carbonate do not appear to have been completely defined. The sea water recipe may furnish some of this information. It is not certain, for example, whether an attempt to prepare aragonite from simple salts will succeed if care is taken to render the materials as free as possible from impurity, especially that in the form of sulphate. If this point has previously been dealt with experimentally, a reference to the work would be welcome.

REVIEWS AND NEW PUBLICATIONS

HADDING, ASSAR, "Glauconite and Glauconitic Rocks," Part IV of *The Pre-Quaternary Rocks of Sweden*. Meddelanden från Lunds Geologisk-Mineralogiska Institution, no. 51, 1932.

This is Hadding's fourth contribution giving results of his studies of the rocks of Sweden, the first being "A Survey of the pre-Quaternary rocks of Sweden," the second considering "The Paleozoic and Mesozoic conglomerates of Sweden," and the third "The Paleozoic and Mesozoic sandstones of Sweden."

The memoir on glauconite and glauconitic rocks may be considered to consist of five parts in the first of which there are considered the distribution of glauconite in the rocks of Sweden and some of the salient facts connected with the distribution. The second part gives the properties of glauconite. In the third part there is given a summary of views held by previous investigators and in the fourth Hadding gives his own conclusions and reflections. The very brief fifth part discusses the relation of glauconite to other sedimentary silicates of iron, but chamosite is the only iron silicate which receives consideration. A short appendix is devoted to glauconite as a fertilizer. A bibliography of fifty-eight authors and seventy-nine titles is given.

Hadding's conclusions on the origin of glauconite are that its formation takes place in shallow, sublittoral, marine waters and that it never forms in fresh waters. Formation is favored in agitated waters under conditions of limited deposition of detritus, particularly fine detritus. It is often formed during negative sedimentation (non-deposition or erosion of the bottom) and its formation is most abundant after periods of negative sedimentation. Glauconite never forms in environments producing forms of animals requiring high temperatures (e.g., corals) and the view is advanced that its formation is favored by relatively low temperatures. A highly oxidizing environment is unfavorable, the favorable environment of formation being one that is slightly reducing or indifferent. Formation is not considered dependent on the presence of organic matter, but organic matter is thought to create favorable conditions for formation. Glauconite is shown to have formed independent of shells of foraminifera and the view is favored that the relationships to such shells are coincidental.

Some of Hadding's conclusions are based on the assumptions that the environmental conditions of formation of the strata containing the glauconite are known and understood. These assumptions may represent a correct understanding of the environments of deposition, but the facts presented in the memoir seem to the reviewer to be possible of other interpretation.

The reviewer considers this work on glauconite a valuable and authoritative contribution and a contribution that does much to advance understanding of this much discussed mineral. It should be read by all students of sediments.

W. H. TWENHOFEL

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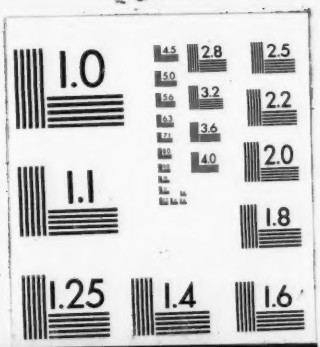
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